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Original Article

AN EFFECT OF TWISTED TAPE WITH NANOFLUID ON THE PERFORMANCE OF DOUBLE PIPE HEAT EXCHANGER: A COMPREHENSIVE REVIEW

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ABSTRACT

The phenomenon of heat transfer is employed in numerous applications such as refrigeration, air-conditioning, food processing, etc. Heat exchangers are used for efficient heat transfer and therefore, the performance of a heat exchanger is important. Cutting edge, innovative and cost-effective techniques are required to achieve efficient heat transfer. Twisted tape (TT) inserts which is a type of passive heat transfer enhancement technique are widely researched. This article delivers an assessment on diverse types of TT in double pipe heat exchangers with different nanofluids. The influence of tape inserts with nano fluids on thermal performance factor (η), Nusselt Number (Nu), friction factor (f) and rate of heat transfer are comprehensively discussed. Application of twisted tape inserts were demonstrated to be more useful in laminar flows w. r. t. turbulent flows. On the contrary, when solid nanoparticles were employed with a high value of φ, heat transfer rate was better in turbulent flows than in laminar flows.

KEYWORDS: Friction Factor, Heat Exchanger, Nanofluid, Thermal Performance Factor & Twisted Tape Insert

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Nomenclature

η	Performance evaluation factor	DR	Depth ratio
α	Attack angle	WR	Width ratio
α’	Wing inclination angle	PR	Pitch ratio
φ	Volume fraction	PI	Performance index
a	Perforated width	BR	Blockage ratio
f	Friction factor	TT	Twisted tape
h	Heat transfer coefficient	TR	Twist ratio
Re	Reynolds Number	ΔP	Pressure drop
Nu	Nusselt Number	WDR	Wing-depth ratio
T_c	Twist length	PWR	Perforated width ratio
W_T	Width of tape	BWR	Baffle width ratio
S_T	Axial spacing	BTR	Baffle twist ratio
D	Diameter of the inner tube	RRP	Relative rib pitch
L	Length of the tube	HDR	Hole-diameter ratio
N	Number of twisted tapes	PVA	Poly vinyl alcohol
d_e	Hydraulic diameter	CC-QTS	Counter current in quadruple counter tape in cross direction

INTRODUCTION

The conversion, utilization and recovery of energy in every industrial, commercial and domestic application involve a heat exchange process. Double pipe heat exchanger (DPHE) is one of the most simple and widely applicable heat exchanger. Due to its simple design and low cost it is commonly used in small scale industries like food, oil, chemical, pasteurizing, reheating, preheating, effluent heating process etc.[1].

Heat loss while transfer is an usual phenomenon and therefore, heat transfer enhancement techniques are required for economical and efficient heat transfer. Heat Transfer Enhancement can be achieved by three methods (i) Active Method (ii) Passive Method and (iii) Combination of these two. In active method, some external power or energy is required for the enhancer to improve heat transfer, such as induced pulsation by cams and reciprocating plungers, mechanical aids, fluid vibration, surface vibration, application of electrostatic fields, application of magnetic field to disturb the seeded light particles in a flow stream, etc. [2]. On the other hand, passive method employs geometrical or surface alterations in the flow channel. These modifications are carried out by inducing inserts or supplementary devices. Swirl flow devices, extended surfaces, treated surfaces, rough surfaces; coiled tubes, surface tension devices, etc. are used in passive heat transfer enhancement pathway [3-6]. The combination of active and passive methods is called as compound method (e. g. rough surface with fluid vibration).

Passive method is the most popularly used method as it employs no external power and enhance the heat transfer rate to a significant extent. Therefore, an optimal heat transfer rate is obtained as economical pumping power. Tube inserts technique is commonly used as one of the routes under passive method. Few examples of tube inserts in a heat exchanger are twisted tape, helical spring, ribs, conical nozzle, conical ring, etc. [7]. Among all the commonly used tube inserts, twisted tape insert is considered as a primary choice and therefore extensively studied and researched by numerous researchers [8-23] worldwide. A typical twisted tape is shown in Figure 1.

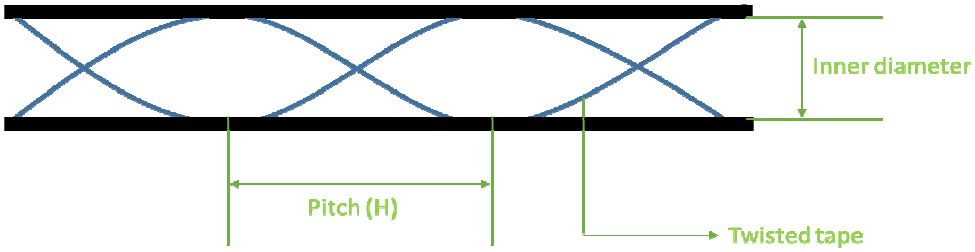


Figure 1: Structure of Typical Twisted Tape

THE IMPACT OF THE COMBINATION OF TWISTED TAPE INSERTS WITH NANOFLUID

Recently, many researchers [8, 10, 12, 15, 18, 24, 25, 26, 27,48] have employed different nano fluids along with twisted tape inserts in diverse heat exchanger to enhance desirable parameters such as heat transfer rate and thermal performance efficiency. Some major studies of the influence of twisted tape inserts in the presence of nanofluid are summarized in Table 1.

Sundar and co-authors [24] and Sharma and co-authors [49] investigated h and f for transitional nanofluid flow inside a circular tube equipped with twisted tape inserts. They reported an enhancement of 23.69% and 44.71% respectively, vis-à-vis employing nanofluid and twisted tape and, twisted tape alone, in the rate of heat transfer at Reynolds Number 9000. Furthermore, they noted an increase of 1.21 times in the value of f while using 0.1% nanoparticle volume

fraction with tape inserts as compared to pure water in plain tube. Sundar et al. [50] assessed the turbulent flow and thermal fields for a combination of magnetic nanofluid and full length tape inserts, in a pipe. They demonstrated an increase of 30.96% in heat transfer rate using the nanofluid (volume fraction - 0.6%) at Reynolds

Number 22000, with respect to plain tube. On the other hand, an enhancement of 18.49% in heat transfer rate and 1.122% in friction factor was noted employing full length twisted tape w. r. t. plain tube.

Table 1: Major Studies about Twisted Tape Inserts with Nanofluid

Type of Research	Specifications of Nanofluid (type/φ/Particle diameter in nm)	Type / Configuration of Twisted Tape	Condition	Findings	Reference
Experimental	• TiO2/Poly-vinyl alcohol • 0.02 • 15	Full length TT Reduced width TT TR = 2 to 5 Width = 12 to 16	800 ≤ Re ≤ 30000	• Nu and f for full length TT with nanofluid were found to be 90-220% and 100-270% higher than plain tube at TR = 3 and 5 respectively • Highest η was obtained up to 1.75 by using reduced width TT at TR = 2, width = 16, φ = 0.5% and Re = 800-30000	[39]
Experimental	• Al2O3/ethylene glycol (EG) • 0.005, 0.01 and 0.015	Conventional TT TR = 2, 3.6 and 5	6000 ≤ Re ≤ 30000	• Using the nanofluid in corrugated tube with TT at TR = 2, φ = 0.5%, maximum η obtained was 4.2	[34]
Numerical (single phase approach)	• Al2O3/H2O • 0-0.04	Conventional TT TR = 3.0, 3.5 and 4.0 Space ratio = 0.3, 0.4 and 0.5 Tape width ratio = 0.5 to 0.9	500 ≤ Re ≤ 25000	• Better heat transfer was obtained in turbulent flow as compared to laminar flow using solid nanoparticles at higher φ • Higher heat transfer was also achieved by using nanoparticles at lower TR • Heat transfer was found to be in direct relation with width of TT and φ in laminar flow	[48]
Numerical (single phase approach)	• Al2O3/H2O • 0.01-0.04 • 100	Twin TT TR = 2.5 to 4.0	10000 ≤ Re ≤ 30000	• The value of Nu was reported to enhance with φ whereas it decreased with increase in TR • Highest values of η were noted as 1.6 and 1.55 respectively at TR = 3.25 and 2.5 • The improvement in η for counter swirl flow was found to be more than co swirl flow	[51]
Experimental	• Al2O3/H2O • 0.01-0.03 • <50	Conventional TT TR = 5 to 20	3000 ≤ Re ≤ 30000	• The value of Nu was improved by 31.28% and f was enhanced by 1.23 times for TT inserts in nanofluid with φ = 0.03 and TR = 5 as compared to water	[32]
Numerical (single phase approach)	• Al2O3 and SiO2-H2O • 0.5-2.0 • 20-50	Helical tape TR = 1.95 to 4.89	150 ≤ Re ≤ 2000	• H2O-Al2O3nanofluid was found to have higher heat transfer enhancement &η vis-à-vis H2O-SiO2 • Heat transfer enhancement was noted to have a direct relation with φ and inverse relation with the diameter of nanoparticle • Nu was found to increase whereas f was reported to decrease with increasing Re	[29]
Experimental Numerical (single phase approach)	• TiO2/H2O • 0.07, 0.14 and 0.21 • 15	Overlapped dual TT TR = 1.5, 2.0 and 2.5	5400 ≤ Re ≤ 15200	• The heat transfer enhancement and η was found to improve by 9.9-11.2% and 4.5% respectively at TR = 1.5, φ = 0.21 vis-à-vis overlapped dual TT without nanofluid	[43]
Experimental	• Cu/H2O • 0.1 and 0.3 • 30 to 50	TT with variable (non-uniform) twist length	7500 ≤ Re ≤ 15000	• Nu and h was found to have higher values in non-uniform TT as compared to uniform TT • h and ΔP was reported to increase when short twist length was introduced at the beginning of TT	[37]

				• A combination of nanofluid with wt% of 0.3 and TT with a profile of low to high was found to improve overall enhancement ratio by 87%	
Experimental Numerical (single phase approach)	• TiO2/H2O • 0.07, 0.14 and 0.21 • 15	Multiple TT with variable arrangements (such as quadruple counter tapes in cross direction)	5400 ≤ Re ≤ 15200	• Highest η was reported as 1.59 while rate of heat transfer was enhanced by 3.52 times and f was increased to 11.7 times in the tube inserted CC-QTS with nanofluid having φ of 0.21, as compared to plain tube with water	[44]
Experimental	• SiO2 and TiO2/H2O • 0.01 to 0.03 • SiO2 = 30 • TiO2 = 50	Conventional TT 5 ≤ TR ≤ 93	5000 ≤ Re ≤ 25000	• The value of h for SiO2/H2O nanofluid with φ = 0.03 was found to be 27.9% higher at TR = 5 w. r. t. water. • The value of h for TiO2/H2O nanofluid with φ = 0.03 was reported to be 11.4% higher for tape with TR = 5 as compared to water.	[47]
Experimental Numerical	• SiO2/H2O • 0.01-0.04	Conventional TT	3000 ≤ Re ≤ 100000	• An increase in the values of h and f was found as 94.1% and 160% respectively at Re = 19046, TR = 5 and φ = 0.03 with nanofluid as compared to water	[45]
Experimental	• TiO2/H2O • 0.005 to 0.03 • 50	Conventional TT TR = 5 to 15	8000 ≤ Re ≤ 30000	• A vital increase in the value of h of about 23.2% was obtained at φ = 0.01 • h was found to have an inverse relation with TR for both nanofluid and water employing TT • The values of h and f were reported to be 81.1% and 1.5 times higher using nanofluid at Re = 23558, φ = 1% and TR = 5 w. r. t. water	[46]
Experimental	• Propylene glycol based CuO/H2O • 0.025, 0.100 and 0.500 • < 50	Conventional TT TR = 0 to 15	1000 ≤ Re ≤ 100000	• The value of h was found to increase to 27.95% at CuO = 0.5% and TR = 5 in a plain tube, which was further enhanced to 76.06% over the base fluid for same Re • An increase of 26.57% in f was reported in same conditions	[33]
Experimental	• Al2O3/H2O • 0.01 to 0.03 • <50	Trapezoidal-cut TT TR = 5 to 20	3000 ≤ Re ≤ 30000	• It was noticed that Nu was enhanced by 34.24% at TR = 5 and 0.03% concentration of nanofluid, w. r. t. water • It was reported that f was increased by 1.29 times at TR = 5 and 0.03% concentration of nanofluid as compared to water	[31]
Experimental	• Al2O3/H2O • 0.01 to 0.03 • < 50	Helical tape TT TR = 5, 10, 15 and 20	3000 ≤ Re ≤ 30000	• It was reported that Nu was increased by 32.91% at TR = 5 and 0.03% concentration of nanofluid, w. r. t. water • It was noticed that f was enhanced by 1.38 times at TR = 5 and 0.03% concentration of nanofluid as compared to water	[30]
Numerical (single phase approach)	• CuO/H2O • 0.02 to 0.04 • 29	Parabolic-cut TT Cut depth = 0.5, 1.0 and 1.5 cm Classical TT TR = 2.93, 3.91 and 4.89	200 ≤ Re ≤ 2400	• It was found that the values of heat transfer rate and f in both classical TT and parabolic-cut TT were directly proportional to TR and inversely proportional to depth of cut • Heat transfer rate was reported to increase with an enhancement in φ of CuO • It was demonstrated that Nu of parabolic-cut TT increased by 10% with a vital increase in f, at cut depth of 0.5 cm and TR of 2.93 w. r. t. classical TT	[52]
Experimental	• γ-Al2O3/H2O • 0.005 to 0.01 • 10 to 20	Conventional TT TR = 3.21 Thickness of TT = 0.5, 1 and 2 mm	150 ≤ Re ≤ 1600	• Nanofluid was found to improve heat transfer performance with increasing thickness of TT. It enhanced f as well	[41]

Hosseinzhad and co-workers [51] studied the turbulence in the flow using twin twisted tapes along with nanofluid in a tubular heat exchanger via numerical pathway. They investigated the co-swirl and counter-swirl flows. They found a direct relation of increase in heat transfer with the nanoparticle concentration and inverse relation with the twist ratio. The performance evaluation criterion was reported to be considerably higher in counter-swirl flow as compared to co-swirl flow. Khoshvaght et al. [37] investigated the influence of twist length on heat transfer enhancement in the presence of nanofluid. They took twisted tape inserts with different lengths such as uniform, low-to-high, high-to-low, low-to-high-to-low and high-to-low-to-high. They reported a vital impact of twist lengths on thermo-hydraulic attributes with 'low to high' twist length having the best characteristics.

In general, it was found that the heat transfer enhancement was better at the outlet of the tube while employing twisted tape inserts with nano fluids on account of the impact of swirl flow; better in the sense that the performance of the device can be improved without enhancing the heat exchanger's size. Moreover, it was noted that a combination of thicker tape inserts with nanofluid has better heat transfer η vis-à-vis thinner inserts. Furthermore, the twisted tapes with alternate axes were found to have superior thermal η w. r. t. conventional inserts.

DISCUSSIONS

This paper discusses the impact of TT of diverse configurations, with nano fluids. TT enhances the convective fluid transferis-à-is plain tube on account of the swirl flow generation. The combined effect of TT insert with nanofluid further increases the heat transfer and conveys even better results when thicker tape is employed with nanofluid.

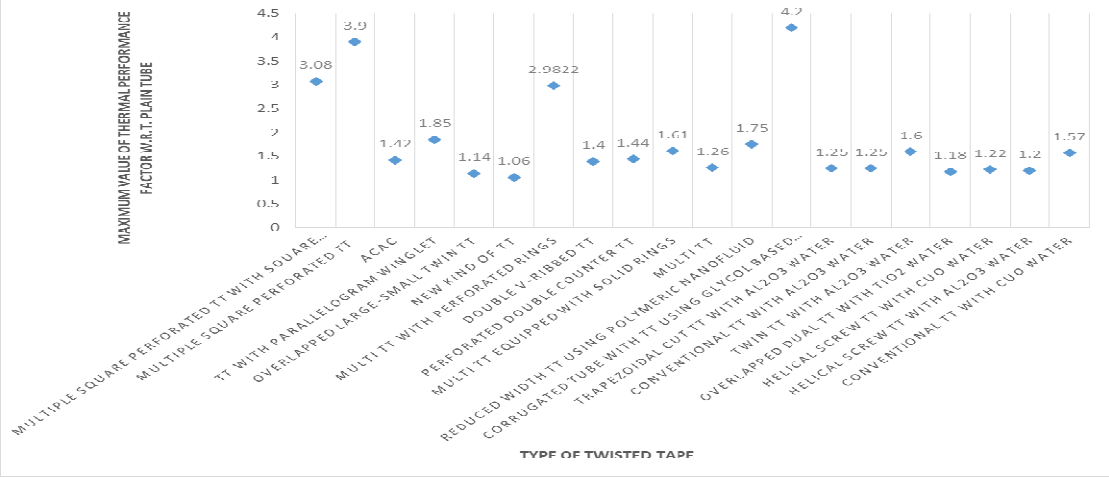


Figure 2: A graph Reflecting the Effects of various TT Configuration and Nanofluid on Thermal Performance Factor ($0.5 \leq TR \leq 7.0$)

A graph is plotted between the types of TT configurations and the maximum values of η (w. r. t plain tube) where all the studies took place at TR ranging from 0.5 to 7, as shown in Fig. 5. It may be noted that the maximum value of η among all the studies reviewed is found to be 4.2 in a corrugated tube equipped with TT in the presence of Al_2O_3/EG nanofluid at TR = 2 and φ = 0.5%. It is on account of synergetic effect of nanofluid along with a high swirling due to low TR.

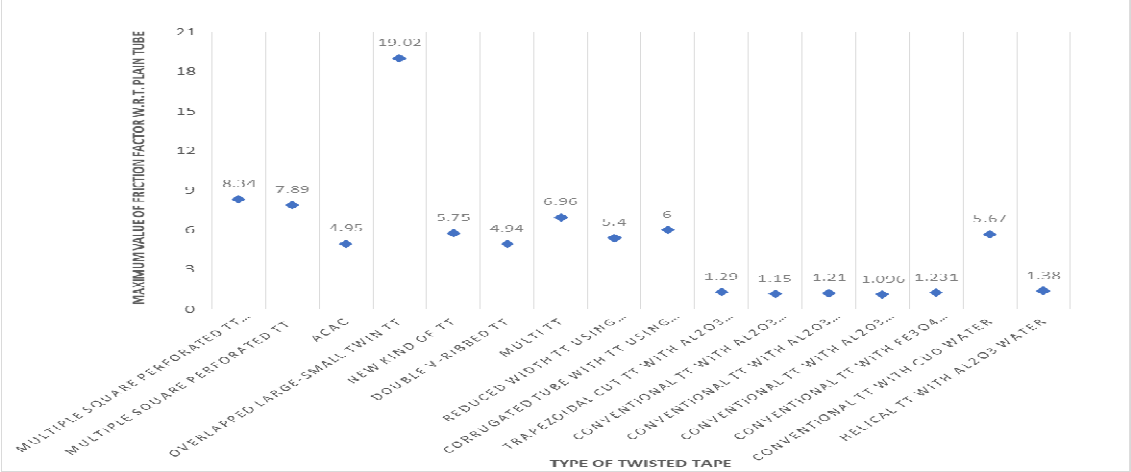


Figure 3: A graph Reflecting the Effects of Various TT Configuration and Nanofluid on Friction Factor (0.5 ≤ TR ≤ 7.0)

Figure 6 is drawn between the types of TT configurations and the maximum values of f vis-à-vis plain tube for all the reviewed research work. The minimum value of f is found as 1.15 in conventional tape inserts in the presence of Al_2O_3 water (φ = 0.03%) at TR = 5 and the flow is in a turbulent region (Re = 3000). It is a plain tube with conventional TT and therefore, the frictional losses are low unlike U-cut, V-cut or grooved shaped inserts and corrugated or spiral tubes.

CONCLUSIONS AND RECOMMENDATIONS

This article sheds light on different types of twisted tape inserts in double pipe heat exchangers with diverse kinds of nanofluids. The impact of tape inserts on the thermal performance factor, Nusselt Number, friction factor and rate of heat transfer were discussed in a holistic manner. It was observed that, in general, the employment of TT enhances Nu, f, η and heat transfer rate vis-à-vis plain tube. Specific conclusions with recommendations are mentioned as under:

- Application of twisted tape inserts were demonstrated to be more useful in laminar flows w. r. t. turbulent flows. On the contrary, when solid nanoparticles were employed with a high value of φ, heat transfer rate was better in turbulent flows than in laminar flows.
- Heat transfer rate was reported to improve with increasing width of TT and volume fraction of nanofluid in laminar flow.
- Nu and f were found to improve with decreasing TR and WR and increasing DR in the tube with cut TT inserts. The same was found to be true in the tape inserts with nanofluid where an enhanced heat transfer was recorded at lower TR. In general, η was found to have an inverse relation with Re.
- An improvement in the rate of heat transfer was noticed with decreasing diameter of the nanoparticles.
- When TT inserts are employed in the presence of nanofluid, Nu was found to increase while f was found to decrease with the rise in Re.

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